
**NASA's Mission Operations
and Communications Services**

**This Description applies only to proposals in response to
NASA's Announcement of Opportunity for Earth System Science
Pathfinder Missions**

AO 98-OES-01

April 1998

TABLE OF CONTENTS

1.0	INTRODUCTION.	1
1.1	Costing Policy	1
1.2	Choice of Service Providers	1
1.3	Evolution and Organization of Services Description	2
1.4	Further Information	2
1.5	Standards	3
1.6	Selection of Services	3
1.7	SOMO Service Categories	3
2.0	TMOD SERVICES, SUPPORT, AND TOOLS.	5
2.1	Deep Space network	5
2.2	Advanced Multi-Mission Operations System.	5
2.3	TMOD Services	7
2.4	Service Costs.	7
2.5	Cost Calculation	10
2.6	AMMOS Tools	12
2.7	Ground Communications Costs.	12
2.8	Assistance with Mission Design	14
3.0	GODDARD SPACE FLIGHT CENTER SERVICES	15
3.1	Ground Network	15
3.2	Tracking and Data Relay Satellite System	15
3.3	GSFC Service Descriptions	15
3.4	GSFC Service Costs	16
3.5	GSFC Point of Contact	23
4.0	REFERENCE DOCUMENTS.	24

LIST OF TABLES

1-1	SOMO Service Categories	4
2-1	Required Telecommunications Parameters and Definitions	6
2-2	Sample Table for Inclusion in Proposal	7
2-3	Standard TMOD Services	8
2-4	Standard TMOD Service, Support, and Tool Fees.	11
2-5	TMOD Provided Mission Operations Tools	13
3-1	Ground Network Facilities	15
3-2	Priced GSFC Services	16
3-3	Command and Telemetry Service Fees	18
3-4	Mission Data Management Service Fees	19
3-5	Navigation Service Fees	20
3-6	Mission Control Fees	20
3-7	Flight Engineering Service Fees	21

NASA's Mission Operations and Communications Services

3-8	Mission Planning Service Fees	21
3-9	Sequence Engineering Service Fees	22
3-10	Ground Communications Costs.	22
3-11	Supporting Service Costs	23

1.0 INTRODUCTION

This document is intended to assist in the preparation of proposals in response to an Announcement of Opportunity (AO) issued by NASA's Office of Earth Science for Earth System Science Pathfinder (ESSP) missions. To facilitate proposal preparation, services are described and costs are tabulated for the facilities operated by two organizations: the Telecommunications and Mission Operations Directorate (TMOD) at the Jet Propulsion Laboratory (JPL) and the Goddard Space Flight Center (GSFC - including Earth stations, Tracking and Data Relay Satellite System (TDRSS), and mission control centers). By providing this summary information, it is hoped that the task of preparing a proposal will be materially simplified.

1.1 Costing Policy

As a matter of policy, NASA will include estimated costs of mission operations communications services, as well as key parameters for mission operations, in the evaluation and selection processes for all space science missions, regardless of whether they are Earth-orbiting or deep space missions. The Office of Earth Science, working with the Office of Space Flight (Code M) and the Space Operations Management Office (SOMO), is implementing this policy:

- in anticipation of formal NASA-wide full-cost accounting,
- to better manage our currently oversubscribed communications resources,),
- to encourage tradeoffs between on-board processing and storage vs. communications requirements, and
- to encourage proposers to design hardware and operations systems which minimize post-launch costs while accomplishing the highest-priority science objectives.

1.2 Choice of Service Providers

Proposers are free to propose using all, some, or none of the NASA-provided services described below. Regardless of this choice, the proposal shall include a rationale for the level of communications services proposed, the basis for costs of communications services, key communications parameters listed below, and rationale and cost basis for mission operations services.

The SOMO-provided communications and operations services are expected to be the most cost-effective services available, i.e. cost- and performance-competitive with any services provided outside NASA. During the proposal evaluation process, the Office of Earth Science and SOMO will review each proposal's performance and cost requirements, and assess the proposed implementation from mission-specific as well as NASA-wide perspectives.

1.3 Further Information

The Space Operations Management Office (SOMO) at the Johnson Space Center is responsible for the functional management of all NASA space operations efforts. SOMO is also responsible for managing NASA's space operations systems, including the Deep Space Network (DSN), the other NASA Ground Stations (GN), the Tracking and Data Relay Satellite System (TDRSS), the NASA Information Services Network, and mission and science operations systems associated with NASA centers. For information about NASA's mission operations and communications service plans, contact:

Dolly Perkins
SOMO Mission Services Manager
Code 720
Goddard Space Flight Center
Greenbelt MD 20771
Fax number: (301) 286-1600
e-mail: dolly.perkins@gsfc.nasa.gov
Phone: (803) 286-6422

1.5 Standards

It is NASA policy that space missions receiving funding from NASA comply with all international and United States regulations, standards, and agreements. Such regulations and standards include those promulgated by:

International Telecommunications Union (ITU)
National Telecommunications and Information Agency (NTIA)
Consultative Committee for Space Data Systems (CCSDS)¹
Space Frequency Coordination Group (SFCG)

Information on the ITU and NTIA regulations can be obtained from the NASA Spectrum Management Office at the Lewis Research Center. Recommended standards for DSN, Ground Network, or TDRSS support can be obtained from Reference 5, the CCSDS home page.

1.6 Selection of Services

A SOMO Service Catalog (Reference 1) has been assembled, permitting users to select combinations of services ranging from full mission operations to basic telecommand and telemetry. Proposals should specify which services and tools they require from the list of standard services found in Sections 2 and 3. However, some services require other

services as a prerequisite (e.g., telemetry frame service is a prerequisite for the packet extraction service).

1.7 SOMO Service Categories

SOMO has moved from a facilities-based support approach to one based upon standard services. Standard services are described in the *SOMO Services Catalog* (Reference 1). These services support both Earth orbiting and deep space science missions. Table 1-1 summarizes SOMO service categories.

Table 1-1: SOMO Service Categories

SOMO Service Category	Brief Description
Command	RF modulation, transmission, and delivery of telecommands to spacecraft.
Telemetry	Telemetry data capture and additional value-added data routing and processing.
Mission Data Management	Data buffering, staging, storing, and archiving.
Experiment Data Products	Higher level data processing providing photo and science visualization products.
Tracking and Navigation	Radio metric data capture and generation of high order navigation products.
Telecom Analysis	Spacecraft link performance, analysis, and prediction.
S/C Time Correlation	Monitors spacecraft clock drift and correlates time to a standard time reference.
Mission Control	Monitors spacecraft health and safety and sends corrective commands.
Instrument Control	Monitors specific spacecraft instruments, sends corrective commands.
Flight Engineering	Performance analysis and anomaly detection of instrument and S/C systems.
Radio Science	S/C Doppler, range, and open-loop receiver measurements at 2, 8, and 32 GHz.
VLBI	Capture of narrowband or wideband very long baseline interferometric data.
Radio Astronomy	Similar to Radio Science except measures natural phenomena.
Service Management	Planning, scheduling controlling, configuring and accounting of system resources.
Mission Planning	Trajectory and mission design, launch analysis, science instrument planning.
Sequence Engineering	Uplink process and sequence design, S/C operations schedule, event prediction.
Ground Communications	Data, voice, and video communications network services.

2.0 TMOD SERVICES, SUPPORT AND TOOLS

The Telecommunications and Mission Operations Directorate (TMOD), located at the Jet Propulsion Laboratory (JPL), is the program office responsible for operating the Deep Space Network (DSN) and the Advanced Multi-Mission Operations System (AMMOS). The DSN comprises a multiplicity of Earth stations and associated operating systems while AMMOS provides many mission related tools and services for: control, monitoring, orbit determination, data analysis, etc. These facilities are available for supporting Earth orbiting and deep space missions.

2.1 Deep Space Network

The DSN consists of control, communications, and test facilities at JPL, and Earth station complexes located near Goldstone, California; Canberra, Australia; and Madrid, Spain. A description as well as the specific characteristics of these stations can be found in Reference 2.

The DSN provides communications services between spacecraft and Earth station complexes together with the ground communications among the complexes and the control center. Control for the network is located at JPL in Pasadena, California. Testing to establish compatibility between the spacecraft's Radio Frequency Subsystem (RFS) and DSN stations is also available at the Development Test Facility (DTF-21) at JPL in Pasadena or by using the Compatibility Test Trailer (CTT) at a remote site. RFS compatibility testing is highly recommended and should be completed approximately one year prior to launch.

DSN 11-meter, 26-meter, 34-meter, and 70-meter diameter antennas operating in the 2, 7, 8, and 32 GHz bands provide radio frequency communications. User costs vary with aperture size and utilization level (see equation 2-1). Generally, DSN services are included in the *Aperture Fee* (see Table 2-4 below).

As a minimum, proposals should contain the set of telecommunications parameters in Table 2-1. While proposers may or may not wish to use a tabular format, the required parameter values should be supplied in a clear, concise, and readily apparent form. Table 2-2 is one example of such a form.

2.2 Advanced Multi-Mission Operations System

Main AMMOS elements are located at JPL; however, specific subsystems may also be placed at user sites. AMMOS offers users a selection of services for spacecraft command and control, data reduction and analysis, and navigation. Because TMOD services are integrated, certain DSN services may be a prerequisite to obtaining AMMOS value-added services.

Table 2-1: Required Telecommunications Parameters and Definitions

Parameter	Units	Description
Maximum S/C Distance	Km	Maximum spacecraft-earth station distance during primary mission.
Encounter 1 Distance	Km	Maximum spacecraft-earth station distance during first encounter.
Encounter 2 Distance	Km	Maximum spacecraft-earth station distance during second encounter.
Encounter N Distance	Km	Maximum spacecraft-earth station distance during N th encounter.
Uplink transmitter Power	Watts	Earth Station Transmitter Output.
Uplink Frequency Band	GHz	Proposed earth-to-space frequency band expressed in GHz.
Uplink Transmitting Antenna	dBi	Gain (or name) of earth stations transmitting antenna (e.g., 34M BWG).
S/C Receiving Antenna Gains	dBi	Gains of all spacecraft receiving antennas.
Telecommand Data Rate	b/s	Maximum desired telecommand data rate.
Telecommand Bit-Error-Rate	-	Required telecommand Bit-Error-Rate (BER).
S/C Receiver Bandwidth	Hz	S/C Receiver's phase-locked-loop threshold bandwidth (2 Blo).
Turnaround Ranging	Yes/No	Statement whether turnaround ranging is required.
SC Transmitting Power	Watts	S/C Power amplifier Output.
Downlink Modulation Format	Name	Format name (e.g., PCM/PM/Bi-Ü, PCM/PSK/PM, BPSK, QPSK, etc.)
Downlink Frequency Band	GHz	Proposed space-to-earth frequency band expressed in GHz.
S/C Transmitting Antenna	dBi	Gains of all spacecraft transmitting antennas.
Downlink Receiving Antenna	dBi	Gain (or name) of earth station receiving antenna (e.g., 34M BWG) .
Telemetry Data Rate	b/s	Maximum desired telemetry data rate.
Error Detecting-Correcting	Name	Telemetry coding (e.g., convolutional, Reed-Solomon, concatenated, etc.).
Telemetry Bit-Error-Rate	-	Required telemetry Bit-Error-Rate (BER).

In addition to its standard services, AMMOS can provide users with specific software tools. Such tools include telecommand encapsulation and protocol verification, mission

analysis software, spacecraft monitoring programs, and data analysis software. A list of available tools can be found in Table 2-5. Fees for AMMOS services and tools will vary with project requirements. Users must assess costs based upon their particular need. The information provided in Tables 2-3, 2-4, and 2-5 below should be used to generate these estimates.

Table 2-2 is a sample of one method for including the required telecommunications parameters in the proposal. Twenty numerical parameter values can be included using only 1/3 of a page.

Table 2-2: Sample Table for Inclusion in Proposal

Parameter	Value	Parameter	<u>Value</u>
Maximum S/C Distance (km)		S/C Receiver Bandwidth (Hz)	
Encounter 1 distance (km)		Turnaround Ranging (Yes/No)	
Encounter 2 Distance (km)		S/C Transmitting Power (Watts)	
Encounter N Distance (km)		Downlink Modulation Format (Name (s))	
Uplink Transmitter Power (Watts)		Downlink Frequency Band (GHz)	
Uplink Frequency Band (GHz)		S/C Transmitting Antenna Gains (dBi)	
Uplink Transmitting Antenna Gains (dBi)		Downlink Receiving Antenna Gain (dBi)	
S/C Receiving Antenna Gains (dBi)		Telemetry Data Rate (b/s)	
Telecommand Data Rate (b/s)		Error Detecting-Correcting Code (Name)	
Telecommand Bit-Error-Rate		Telemetry Bit-Error-Rate	

2.3 TMOD Services

TMOD offers an integrated set of AMMOS and DSN services. A service list and description appear in Table 2-3 below. Users can select only those services needed to support their project. However, some services require others to obtain or condition data before they are available.

2.4 Service Costs

As NASA moves to a full cost accounting model, it is important that the pro-rata share of each service's cost be determined and identified in each proposal. Users are free to select only those services that they require, but they also have the burden of estimating the costs for those services. The following information is intended to assist in estimating those costs.

Table 2-3: Standard TMOD Services

Service Types	Brief Description
Command: Command Radiation End-to-End Command Delivery	<i>RF modulate and transmit CLTUs to user spacecraft. Error-free delivery of command files to spacecraft using COP-1 protocol.</i>
Telemetry: Frame Packet Channel Data Set	<i>Provides frame reconstruction and routing options for CCSDS compliant formats. Extracts packets from frames by earth received time or sequence number. Extracts data samples from packets based upon pre-established criteria. Provides Level-O products for selected instruments and observation cycles.</i>
Mission Data Management: Short Term Data Retention Long Term Data Repository Archive Product Preparation	<i>Data buffering and staging (up to 1-week) to ensure delivery. Data storage and retrieval for life-of-mission. Prepares data products for long-term data archival.</i>
<u>Experiment Data Products</u> <u>Level 1 processing</u> Higher Level Processing Photo Products Science Visualization	<i>Generates Level-1 experiment data. Generates Level-2 (or higher level) data products. Provides photo product enhancement and annotation at any level. Data visualization and animation using navigation, ephemeris, CAD, and remotely sensed data/imagery. 3D science data rendering and animation. Sense of Active Presence – virtual reality based on telemetry, science data, models, etc.</i>
Tracking and Navigation Radio Metric Measurement Data Conditioning/Validation Orbit Determination Trajectory Analysis Maneuver Plan/Verification Ephemeris Modeling & Calibration Ancillary Data	<i>Provides raw, uncalibrated radio metric observables. Validated, calibrated, radio metric data. State vectors representing a solution obtained from conditioned data. Flight path prediction, reconstruction, or optimization. Provides maneuver analysis required for project planning. Ephemerides for planets, planetary satellites, comets and asteroids. Provides terrestrial frame, media gravity, & cartography calibration data. Ephemeris, spacecraft, and instrument data for use with science observations.</i>
Telecom Analysis	<i>S/C communications link performance analysis, prediction and monitoring.</i>
S/C Time Correlation	<i>Monitors S/C clock drift and correlates S/C time to a standard time reference.</i>
Mission Control	<i>Monitors spacecraft health and safety, sends corrective commands.</i>
Instrument Control	<i>Monitors specific spacecraft instruments, sends corrective commands.</i>
Flight Engineering Spacecraft Performance Analysis Spacecraft Anomaly Response Payload Analysis	<i>Provides system level performance analysis of spacecraft. Detection and isolation of spacecraft anomaly and initiation of recovery actions. Provides system level performance analysis of instrument.</i>
Radio Science	<i>Doppler, range, and open-loop receiver data at 2, 8, and 32 Ghz.</i>
VLBI	<i>Provides narrowband or wideband very long baseline interferometric data.</i>
Radio Astronomy	<i>Similar to Radio Science data except measurement of natural phenomena.</i>
Service Management Service Configuration Service Accounting Service Fault Service Security	<i>Planning, scheduling, controlling, and configuring of TMOD resources. Provides input/output data accountability pursuant to service agreement. Fault detection-correction and logging using monitor data. Provides for system security pursuant to service agreement.</i>
<u>Mission Planning</u> <u>Mission Scenario Planning</u> <u>Science Observation Planning</u>	<i>Trajectory design and optimization, mission plan development, trajectory ancillary data for science planning, launch vehicle analysis, and target specification. Science/Instrument planning: ops scenarios, instrument data for observations, etc.</i>
<u>Sequence Engineering</u>	
Ground Communications	<i>Design of the uplink process including evaluation of on-board autonomy and automation. Provides science, engineering, and navigation activity request integration, sequence and command generation, spacecraft operations schedule, and predicted spacecraft events.</i> <i>Provides data, voice, and video communications network services.</i>

2.4.1 DSN Aperture Fees

The algorithm for computing DSN *Aperture Fees* embodies incentives to maximize DSN utilization efficiency. It employs *weighted hours* to determine the cost of DSN support. The following equation can be used to calculate the *hourly Aperture Fee* (AF) for DSN support.

$$AF = R_B [A_W (0.9 + F_C / 10)] \quad (2-1)$$

where:

AF = weighted *Aperture Fee* per hour of use.

R_B = contact dependent hourly rate, adjusted annually (\$560/hr. for FY98).

A_W = aperture weighting:

= 0.1 for 11-meter stations (stations have very limited capability).

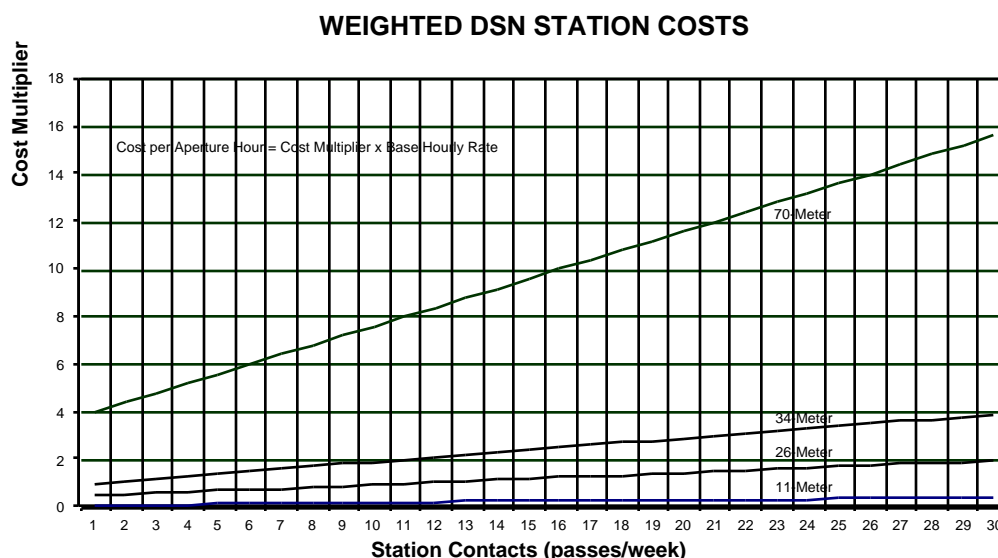
= 0.5 for 26-meter stations.

= 1.0 for 34-meter stations.

= 4.0 for 70-meter stations.

F_C = number of station contacts, (contacts per calendar week).

The *weighting factor* graph below shows relative antenna costs. A *station contact* may be any length but is defined as the lesser of the spacecraft's viewperiod or 12 hours. Total DSN cost is obtained by partitioning mission into calendar weeks and summing the *Aperture Fees*. This total cost can be obtained by grouping weeks having the same requirement, multiplying by weighted *Aperture Fee*, and summing over the mission's duration .



2.4.2 AMMOS Fees

Computing AMMOS services fees is more complex than DSN costs because each mission's requirements depend upon its specific objectives. Nevertheless, it is

possible to estimate costs for some services. AMMOS service cost, C_S , is comprised of two components.

$$C_S = C_M + C_O \quad (2-2)$$

where:

C_M = a Phase C/D cost for hardware and software modifications.

C_O = a Phase E mission operations cost for each service.

C_M represents a setup effort for preparing the AMMOS system to perform the service during the mission's operational phase. Setup costs include both labor and hardware components. Labor costs are expressed in *Work Months* (WM) corresponding to the effort of one person, possessing the requisite skill level, working for one month. Hardware costs are expressed in FY98 dollars. Total preparation costs, C_M , should be shown during the years that the work is underway, usually a 2-3 year period prior to launch.

C_O is the incremental effort needed to perform the named service throughout the mission's operational phase (Phase E). Generally, C_O represents a labor cost. In Table 2-4, it is expressed in FY98 dollars where \$13K = 1 WM. C_O represents the cost of the service, for the specified time interval or named capability. This component appears as a Phase E service cost during each year that the service is provided.

Several AMMOS service fees, listed in Table 2-4 below, are based upon prior TMOD estimates for six missions: VSAT, Genesis, Europa Orbiter, CONTOUR, New Millennium DS-1, and DS-3. These cost estimates were analyzed to obtain an average cost for each service. Where prior estimates did not exist, a maximum and minimum fee was computed. Table 2-4 shows the average value of calculated fee range. Fees in Table 2-4 can be used as a guideline in proposal preparation. AMMOS costs are separate and distinct from the aperture fees for DSN stations described above in Section 2.4.1.

2.5 Cost Calculation

Caveat:

Cost numbers supplied in this Section are for planning purposes only. To ensure accurate application of this information and to validate cost estimates please contact the TMOD representative listed in Section 2.8. During Phase 2, service costs should be validated by contacting the TMOD representative.

Total TMOD service cost is obtained by summing the DSN and AMMOS fees. DSN cost (*Aperture Fee*, AF in \$/Hr.) is calculated by selecting a specific aperture and then determining the number and duration of tracking passes required to satisfy project

Table 2-4: Standard TMOD Service, Support, and Tool Fees

Service Name	DSN Costs	Typical AMMOS Costs		
	Post-Launch	Pre-Launch		Post-Launch
	Services In Aperture Fee	Work Force (Work Months)	Hardware (FY98 \$)	Support Cost (FY98 \$)
Command: <i>Command Radiation</i>	Aperture Fee	9	\$20K	\$100/Up-link Hour
End-to-End Command Delivery	-	-	-	-
Telemetry: Frame	Aperture Fee	4	\$40K	\$40/Dn-link Hour
Packet	-	Incl. in above	Incl. in above chg.	Incl. in above
Channel	-	chg.	-	chg.
Data Set	-	6	-	-
Pathological Data	Aperture Fee	Incl. in above	Call for price	-
		chg.		Call for price
		Call for price		
Mission Data Management: Short Term Data Retention	Aperture Fee	10	\$40K + \$2K/10 GB	\$7K/Month
Long Term Data Repository	-	10	\$40K + \$2K/10 GB	\$7K/Month
Archive Product Preparation	-	4/Instrument	-	\$2.5K/Inst./Month
Experiment Data Products: Level 1 Processing	-	8/Instrument	\$25K	\$2.5K/Month
Higher Level Processing	-	Min. 6/Instrument	\$50K	\$5K/Month
Photo Products	-	2/Instrument	\$2.5K	\$1.3K/Month
Science Visualization	-	2/Visualization	\$5K	\$12K/Month
Tracking and Navigation: Radio Metric Measurement	Aperture Fee	-	-	-
Data Conditioning/Validation	Aperture Fee	-	-	-
Orbit Determination	-	23	\$40K	\$312K/Year
Trajectory Analysis	-	19	\$23K	\$250K/Year
Maneuver Plan/Verification	-	1.3	-	\$16K/Maneuver
Ephemeris	-	2.5	-	N/C
Modeling & Calibration	-	N/C	-	N/C
Ancillary Data	-	2.5	-	\$30K/Year
Telecom Analysis:	-	15	\$10K	68K/Year
S/C Time Correlation:	-	1.3	-	1.3K/Year
Mission Control:	-	10	\$10K/User station	160K/Year
Instrument Control:	-	15/Instrument	\$50K	\$5K/Inst./Month
Flight Engineering:	-	35	\$10K/User station	\$56K/Month
Radio Science:	Aperture Fee	-	-	-
VLBI:	Aperture Fee	-	-	-
Radio Astronomy:	Aperture Fee	-	-	-
Service Management: Resource Allocation	-	4	4	\$16K/Year
Service Configuration	Aperture Fee	-	-	-
Service Accounting	Aperture Fee	-	-	-
Service Fault	Aperture Fee	-	-	-
Service Security	-	2	2	\$1K/Month
Mission Planning:	-	24	-	\$6K/Month
Sequence Engineering:	-	24	\$10K	\$24K/Month
Engineering Support: System Engineering	-	16	-	\$43K/Year
System Integration & Test	-	7	-	-
Network and Hardware Eng.	-	4	-	-
System Administration	-	13	-	\$156K/year
Telemetry End User Tools:	-	10	-	43K/Year
Ground Communications:	-	1	\$100K	\$55K/Year

Notes: - Service not available; N/C = No Charge; Aperture Fee = Service included in fee calculated from Section 2.4.1;

1 Work Month (WM) = 13K in FY 98 dollars; Work Mo./Year = Number of Work Months in a calendar year.

navigation and science objectives. Each tracking pass must be increased in length by 45 minutes (30 min. precal + 15 min. postcal). Once pass length and number of passes is determined, multiply the aggregate hours by the hourly *Aperture Fee* computed using equation (2-1).

Total AMMOS costs are the sum of all service setup and incremental fees and depend upon the number and duration of the services required. Projects must first identify the specific AMMOS services that they need. They also need to determine the number of years, and fractions thereof, that these services will be required during the operational phase. Total Phase E cost for all services is calculated by multiplying the incremental fee for each service, found in the rightmost column of Table 2-4, by the total time that service is required and then summing over the set of services. Total Phase C/D expenses are labor plus hardware setup costs for each service summed over the set of services. Phase C/D costs should be distributed over a 2-3 period prior to launch.

AMMOS labor costs are stated in *Work-Months* to insulate the data from inflation factors. Users need only multiply the total number of *Work-Months* required for each service by the value for the year specified in the AO. For FY98, a burdened *Work-Month* is approximately \$13K. Hardware and Phase E costs are shown in FY98 dollars and will need to be adjusted in order to be applicable to a different year.

2.6 AMMOS Tools

In addition to services, AMMOS can also provide users with tools needed to operate their mission. Tools are distinguished from services in that the former are software and hardware elements created for or adapted to a specific mission whereas the latter are those activities defined in Table 2-3 above. Tools are transferred to the flight project for operation by their personnel during the mission. Table 2-5 lists some AMMOS provided tools and includes a short description.

Because each mission is unique, it is difficult to provide apriori tool prices. Generally, AMMOS personnel need to confer with cognizant project personnel to determine specific tool requirements. Thereafter, it should be possible to quote a price for the product. If a tool's specification can be completed by the end of Phase B, work can commence at the start of Phase C/D so that the tool will be available at launch.

2.7 Ground Communications Costs

TMOD's Ground Communications Facility (GCF) provides data lines between the several DSN complexes and JPL. The Marshall Space Flight Center (MSFC) also connects the GCF to the NASA Integrated Services Network (NISN). NISN maintains communications lines among NASA centers and to institutions such as the European Space Agency's control center, ESOC, in Darmstadt, Germany.

Table 2-5: TMOD Provided Mission Operations Tools ¹

TOOL NAME	TOOL FUNCTION
Command Command Delivery Automated Command Tracker	Command data encapsulation and uplink protocols conforming to CCSDS. Automated command file tracking, review, and approval process.
Telemetry	Turnkey telemetry system dedicated to acquisition, processing, monitoring, storage, and distribution of telemetry data (up to level-0), including CCSDS frame, packet, and channel services.
Mission Analysis Telecommunications Analysis S/C Performance Analysis	Monitor and predict the uplink and downlink telecommunications performance. Analysis capability for spacecraft and science instrument performance and health based upon telemetry data acquired from the various subsystems.
Mission Data Management Data Management Data Products	Data catalog, query, access, and data storage capabilities. Tools to create data products containing engineering and science data sets and to record them on a variety of magnetic and optical media.
Experiment Product Science Data Processing Sense of Active Presence Science Data Visualization Photo Product	Generates level 1A&B and higher level products from level-0 data. Provides virtual reality images based on telemetry, science data, models, etc. Converts science data products for display or printing for visual interpretation. Creation of photo products with visual enhancement and annotation.
Cartographic	Software for precise cartographic projections, elevation maps using stereo imagery, and cartographic projections for target bodies.
Tracking and Navigation Navigation Ancillary Data	Software supporting radiometric data conditioning, orbit determination, trajectory analysis, and maneuver planning and verification.
Mission Control	Displays engineering telemetry data to monitor spacecraft health and safety.
Instrument Control	Displays engineering telemetry data to monitor instrument health and safety.
Planning and Scheduling Mission Design Science Observation Planning Sequence Planning	Mission event simulation, graphical displays of spacecraft trajectory and the motion of various planetary bodies. On-board and on-the-ground capability for science observation planning. Includes target body modeling, photometric modeling, etc. Provides sequence generation, validation, and review capabilities for standard mission commanding scenarios.
Test and Simulation Data Simulation Test Spacecraft Simulation Test	Generation of test data, i.e. simulated RF signals, spacecraft telemetry frames and packets, science data frames, and other data artifacts. Simulates spacecraft's behavior in response to control and external events.
Integrated Ground Data System	Provides turnkey system including computer platforms and a complete suite of tools adapted for mission specific needs.
Instrument Development Ground Support Equipment Flight Software Development Instrument Modeling Calibration / Decalibration Data Compression / Decompression	Instrument Ground Support Equipment (IGSE) and environment software. Tools and development environment for instrument software. Provides mathematical models of remote sensing instruments. Software supporting calibration analysis for science instruments. Selection and development of science data compression algorithms including end-to-end data system simulation – photon to final science product.

NOTES:

1. **Contact TMOD service representative for Tool pricing information.**

If service to facility not now connected to the GCF or NISN is required, additional lines must be procured. Under full cost accounting, such additional common carrier fees must be acknowledged by the requesting project. In calculating line costs, users should determine the monthly cost, for a line of the needed capacity, from NISN's gateway at MSFC to the desired location. That cost should be multiplied by the number of months that the special service is required. TMOD personnel can assist in obtaining such estimates.

2.8 Assistance with Mission Design

Prospective TMOD service users can obtain additional information about TMOD's services and capabilities by consulting Reference 2 below or by contacting the Future Missions Planning organization in TMOD's Plans and Commitments Office. TMOD's Future Missions Planning personnel can assist individuals preparing proposals by: identifying future capabilities and services, preparing a preliminary communications link analysis, describing TMOD requirements placed on users of its facilities, and assisting in the preparation of cost estimates for TMOD services. For such support please contact one of the persons listed below:

Warren L. Martin	Gary K. Noreen
Manager	Deputy Manager
TMOD Future Missions Planning Office	TMOD Future Missions Planning Office
Phone: (818) 354-5635; FAX (818) 393-1692	Phone: (818) 354-2699; FAX (818) 393-1692
e-mail: warren.l.martin@jpl.nasa.gov	e-mail: gary.k.noreen@jpl.nasa.gov

3.0 GODDARD SPACE FLIGHT CENTER SERVICES

The Goddard Space Flight Center (GSFC) is responsible for operating the Ground Network, and the Tracking and Data Relay Satellite System (TDRSS), and for providing mission operations and ground data system services. Generally, these services are for the support of Earth orbiting missions.

3.1 Ground Network

GSFC's Ground Network provides communications between spacecraft and a number of Earth stations. There are 8 antennas varying in size from 5 to 18 meters in diameter. Table 3-1 summarizes station locations, size, and operating frequencies. For additional information describing the Ground network, consult Reference 3 entitled: *NASA/GSFC/WFF Ground Network Resources*.

Table 3-1: Ground Network Facilities

Location	Antenna Diameter (Meters)	Uplink Frequency (GHz)	Downlink Frequency (GHz)
Fairbanks, Alaska	5 M	2	2
	8 M	2	2
Wallops, Virginia	5 M	2	2
	8 M	2	2
	18 M	2	1.4 and 2
Mayaguez, Puerto Rico	5 M	2	2
McMurdo, Antarctica	10 M	2	2 and 8
Svalbard	11 M	2	2 and 8

3.2 Tracking and Data Relay Satellite System

GSFC operates the Tracking and Data Relay Satellite System (TDRSS) which is designed to support Earth orbiting missions. Relay satellites in geosynchronous orbit communicate with user spacecraft through single or multiple access channels. TDRS control is at White Sands, New Mexico via GSFC. A special transponder, providing a spread spectrum downlink signal, is required on all user spacecraft communicating through the TDRS multiple access channel. The same transponder can operate in a non-spread spectrum mode for communications directly with an Earth station.

For additional information describing the TDRSS, consult Reference 4 entitled: *Space Network Users' Guide*.

3.3 GSFC Service Descriptions

GSFC provides the full range of communications, mission operations, and data processing services for a wide range of space and Earth science missions. These services include the

development or arrangement of systems performing the service, development of operations procedures and training of operators and users, and provision of the actual service to an on-orbit mission. Most of these services are performed on the ground; however, a subset of some services could be performed on the spacecraft.

Prices of many GSFC services depend upon mission specific requirements. Table 3-2 shows the GSFC services for which cost information is available. Priced services are for the space/ground communications services and for some of the mission operations services that are less influenced by mission requirements.

Table 3-2: Priced GSFC Services

SOMO Standard Service Category	Priced GSFC Services
Command	Ground Station Services TDRSS Services
Telemetry	Ground Station Services TDRSS Services
Mission Data Management	Data Capture Data Distribution and Archiving Level Zero Processing
Experiment Data Products	Mission Unique
Tracking and Navigation	Mission Design Trajectory Design and Maneuver Support Planning Aids
Telecom Analysis	TBD
S/C Time Correlation	Real Time Command and Telemetry Processing
Mission Control	Real Time Command and Telemetry Processing Ground Attitude Determination
Instrument Control	Real Time Command and Telemetry Processing
Flight Engineering	Trend Analysis
Radio Science	Not a GSFC Service
VLBI	Not a GSFC Service
Radio Astronomy	Not a GSFC Service
Service Management	Included as part of each priced service
Mission Planning	Mission Planning
Sequence Engineering	Command Management
Ground Communications	Ground Communications

3.4 GSFC Service Costs

This section provides costs of GSFC operations services, which do not need a detailed understanding of the mission's requirements. Users of these prices are encouraged to contact the GSFC person identified in Section 3.5 to verify that the prices are used appropriately and to calculate service costs that are based on specific mission requirements.

Caveat:

Cost numbers supplied in this Section are to be used for step 1 proposals in response to this Announcement of Opportunity only. To ensure accurate application of the information and to validate cost estimates, please contact the GSFC representative listed in Section 3.5. During the Phase A concept study, service costs should be validated by contacting the GSFC representative.

Mission operations and data services described herein contain assumptions and limitations on the missions to which they may be applied. In general, these prices are valid for low earth orbiting survey missions with one instrument or with multiple instruments operating together. Prices assume the use of CCSDS Recommendations for command and telemetry data and a robust spacecraft design so that an operations team is needed only for a standard 40-hour workweek during normal operations.

Examples of cases where most of these prices would not be applicable include: missions whose instrument(s) must be targeted, missions having frequent maneuvers, or missions lacking adequate onboard resources and which require special care in planning and commanding. Note that missions having a significant amount of design commonality with projects currently supported by GSFC, may incur significantly lower costs for some mission operations services.

All of the services described in Section 3 can be provided by GSFC. Additionally, with the exception of TDRSS services, GSFC can provide users with systems permitting them to provide services directly.

All prices are in FY 98 dollars.

3.4.1 Command and Telemetry Services.

GSFC provides command and telemetry services to missions in the vicinity of Earth. A summary of command and telemetry service fees appears in Table 3-3.

Except where noted, GSFC Command and Telemetry services provide command uplink, telemetry reception, and tracking and ranging. The TDRSS command and telemetry services are “bent pipe” where TDRSS accepts and delivers data bits at the mission data rate. The Ground Network can deliver similar services and, in addition, provide a store-and-forward service for commands as well as CCSDS telemetry services including virtual channel separation and deferred delivery.

Table 3-3: Command and Telemetry Service Fees

GSFC Command and Telemetry Services		Station Fees (FY 98 \$)
Ground Network Station Services		Per pass
	8 m S-band in Wallops Virginia and Fairbanks Alaska	300
	10 m S/X-band McMurdo Antarctica	800
	5 m S-band at Fairbanks, Wallops, and Puerto Rico	250
	11 m S/X-band Svalbard, Fairbanks	800
TDRSS Services		Per hour
	TDRSS Single Access (S or Ku-band)	\$1500
	TDRSS Multiple Access (S-band) forward service	\$480
	TDRSS Multiple Access (S-band) return service	\$180

a. The TDRSS cost assumes flexible support, where the user requests contacts that permit NASA, at its option, to schedule service at any time during the period of a single orbit of the user mission. If the requests are not flexible, the cost is significantly higher.

b. Tracking is not available from the 5 m S-band stations.

Prices for TDRSS apply to the time that a user spacecraft is in contact with the relay satellite. The ground station prices assume a low earth orbit, with a pass time of 15 minutes or less.

3.4.2 GSFC Mission Data Management Services

These services perform various levels of processing on the mission data, including level zero processing (removal of the artifacts of the space/ground transmission) and higher level processing into science products. The mission data management services also include the storage of data and the interface to users of the data.

GSFC provides data services from the capture of data at the space/ground link pick-up point through to the delivery and archival of science data products. Most experiment data product service costs depend on mission requirements and cannot be priced without them. Table 3-4 summarizes these fees.

Table 3-4: Mission Data Management Service Fees

Service	Development Cost	Yearly Operations Costs	Notes
Level Zero Processing: Removal of the artifacts of the space/ground communication and restoring the data to the form in which it left the instrument. Includes recording the data and storing it for a moderate time to prevent subsequent loss of data prior to archiving.	\$94 K \$44 K ops prep cost	\$55 K	Assumes use of CCSDS data standards. Assumes 5 Gbits per day.
Data Distribution and Archiving: Stores the data for the life of the mission. Provides reliable distribution of the data to users and makes data available over the internet.	\$308 K \$44 K ops prep cost	\$110 K	Assumes up to 2 Gbits per day. Data delivered within 24 hours of receipt on the ground.
Data Distribution and Archiving: Stores the data for the life of the mission. Provides reliable distribution of the data to users and makes data available over the internet.	\$600 K \$44 K ops prep cost	\$340 K	Assumes 50 Gbits per day, two year mission 2 TB online storage, the rest offline

3.4.3 Navigation Services

GSFC can provide tracking and navigation services for a wide range of missions in Earth orbit and beyond (for example, missions to L1 or L2). Tracking services are included in the ground station and TDRSS prices in Section 3.4.1. Navigation service costs depend on mission requirements. To price navigation services, the mission's requirements need to be defined. Missions, for which prices in Table 3-5 are applicable, have the following characteristics:

- a. Low Earth orbit
- b. GPS used for position information
- c. Survey mission where instruments are not targeted, but instead are on all of the time, possibly changing modes based on orbital events (such as sun/shadow transitions)
- d. Pointing accuracy no better than 1 arc minute.
- e. Few operations constraints
- f. Ground station space/ground communications

A navigation service fee schedule appears in Table 3-5.

Table 3-5: Navigation Service Fees

Service	Fee	Notes
Mission Design: This support consists primarily of orbit analysis including launch window analysis, orbit lifetime analysis, and coverage studies. This service also supports spacecraft design efforts by providing predicted orbit/attitude profiles, and supports the principal investigator in defining science viewing opportunities.	\$55 K pre-launch \$11 K Launch and early orbit support	Does not include launch vehicle analysis, which is assumed to be provided by launch services provider.
Trajectory Design and Maneuver Support: This service provides analysis and preparation of maneuver plans for initial maneuvers to place the spacecraft in its mission orbit following launch and periodic stationkeeping maneuvers.	\$198 K pre-launch analysis and development \$88 K Launch and early orbit support \$77 K per year of routine ops support	Stationkeeping maneuvers occur monthly.
Planning Aids: Planning aids are required for scheduling spacecraft and science activities. These typically include orbit event prediction and ephemeris files. Data is distributed over the web except for acquisition data required by ground stations, which are sent directly.	\$110 K pre-launch analysis and development \$22 K Launch and early orbit support \$44 K per year of routine ops support	GPS navigation solutions provided in telemetry are assumed to provide an accurate velocity which allows accurate propagation of the orbit. Typical products include ground station contact times, South Atlantic Anomaly predictions, predicted orbit tracks, and eclipse times.

3.4.4 GSFC Mission Control Services

GSFC Mission Control Services (Table 3-6) monitor the health and safety and control the spacecraft. These services also include instrument health and safety monitoring and spacecraft time correlation.

Table 3-6: Mission Control Service Fees

Service	Development (FY98 \$)	Yearly Operations (FY98 \$)	Notes
Real Time Command And Telemetry Processing: Processing real time housekeeping telemetry, and issuing real time commands and command loads.	\$308 K \$330 K ops prep cost	\$97 K	Assume a survey mission with few operational constraints. Includes redundancy. Time correlation to 1 millisecond.
Ground Attitude Determination: Real time attitude determination software and analysis expertise is provided for real time attitude health and safety monitoring. Analysis support is required during early orbit operations to verify onboard performance and for anomaly investigation.	\$110 K \$22 K ops prep cost	\$22 K for launch and early orbit plus \$11 K per year for routine operations	No inflight calibration or sensor alignment of the onboard attitude system is included, as this is dependent on mission sensor complement and attitude knowledge requirements.

3.4.5 Flight Engineering Services

Flight engineering services analyze spacecraft subsystem performance. Service fees appear in Table 3-7.

Table 3-7: Flight Engineering Service Fees

Service	Development (FY98 \$)	Yearly Operations (FY98 \$)	Notes
Trend Analysis: Processing of housekeeping data over time to identify trends and to characterize subsystem performance.	\$88 K \$82 K ops prep cost	\$44 K	Assume a survey mission with few operational constraints. Number of parameters processed less than 2000.

3.4.6 Mission Planning Services

Mission planning services (Table 3-8) integrate the activities of the instrument, spacecraft and space/ground link into a conflict-free schedule.

Table 3-8: Mission Planning Service Fees

Service	Development (FY98 \$)	Yearly Operations (FY98 \$)	Notes
Mission Planning: Generating conflict free mission plan among instrument, spacecraft and space/ground link.	\$132 K \$110 K ops prep cost	\$73 K	Assume a survey mission with few operational constraints. Single instrument or consolidated instrument set. Survey mode operations. Ground station.

3.4.7 Sequence Engineering Services

Sequence engineering, also known as command management, converts a schedule into a constraint checked set of properly formatted command loads. Fees are found in Table 3-9.

Table 3-9: Sequence Engineering Service Fees

Service	Development (FY98 \$)	Yearly Operations (FY98 \$)	Notes
Command Management: Generating and constraint checking command loads for spacecraft.	\$146 K \$110 K ops prep cost	\$66 K	Assume a survey mission with few operational constraints. Several loads per week.

3.4.8 Ground Communications Services

The GSFC space/ground communication service costs do not include the cost of moving the data to and from the pick up point - GSFC for TDRSS, the ground station for the others. The Marshall Space Flight Center (MSFC) is responsible for providing communications service using the NASA Integrated Services Network (NISN). NISN maintains communications lines among NASA centers and to other institutions. If service to a facility not now connected to NISN is required, additional lines must be procured. Under full cost accounting, such additional common carrier fees must be covered by the requesting project. In calculating line costs, users should determine the monthly cost, for a line of the needed capacity, from the closest NISN gateway to the desired location. That cost should be multiplied by the number of months that the special service is required. GSFC personnel can assist in obtaining such estimates. Table 3-10 provides prices for a 64 kbps service between two destinations. This service would be appropriate for missions generating less than 3 Gbit of data per day and which can wait up to 24 hours for complete data delivery.

Table 3-10: Ground Communications Costs

Space/Ground Pickup Point	Mission System Location	Price per Month
Fairbanks	GSFC	\$1660
Fairbanks	Los Angeles	\$890
Wallops	GSFC	\$840
Wallops	Los Angeles	\$730

3.4.9 GSFC Supporting Services

GSFC can provide or arrange for other space operations services as required to meet unique mission requirements. These supporting services include:

- a. spectrum licensing
- b. systems engineering
- c. end-to-end testing and mission readiness testing
- d. simulators

A low fidelity simulator is priced in Table 3-11.

Table 3-11: Supporting Service Costs

Service	Development (FY98 \$)	Yearly Sustaining Engineering (FY98 \$)	Notes
Low Fidelity Simulator: Accepts and verifies commands and loads; generates simulated telemetry data, both real time recorded. Used for testing and training the operations team.	\$110 K	\$22 K	Assumes CCSDS. Does not model the instruments or spacecraft subsystems.

3.4.10 GSFC Provided Systems

All GSFC services, with the exception of those associated with TDRSS, can be provided to users for their operation. For those services that are priced in Sections 3.4.2 through 3.4.8, the cost of the provided system includes the development or prelaunch cost, minus any identified operations preparations costs.

3.5 GSFC Point of Contact

Prospective GSFC service users can obtain additional information about GSFC's services, capabilities, and prices by contacting:

Steve Tompkins
Phone: (301) 286-6791; FAX (301) 286-1602
e-mail: steven.tompkins@gsfc.nasa.gov

This point of contact can assist individuals preparing proposals by: identifying future capabilities and services, preparing a preliminary communications link analysis, describing GSFC requirements placed on users of its facilities, and assisting in the preparation of cost estimates for GSFC systems or services.

4.0 REFERENCE DOCUMENTS

Prospective users of SOMO facilities can obtain additional information from the following documents:

1. *Services Catalog*, NASA Space Operations Management Office, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, Code TA, 2101 NASA Road 1, Houston, Texas 77058.
Copies of the document are available at:
<http://www.jsc.nasa.gov/somo/products.htm>
2. *AMMOS and DSN Support of Earth Orbiting and Deep Space Missions*, Document D-13973, Telecommunications and Mission Operations Directorate, Jet Propulsion Laboratory, Pasadena, California, **Latest Edition**.
Copies of the document are available at: ***<http://deepspace1.jpl.nasa.gov/advmisss>***
3. *NASA/GSFC/WFF Ground Network Resources*.
Copies of the document are available at: ***TBD***
4. *Space Network Users' Guide*, **Latest Edition**.
Copies of the document are available at: ***<http://www530.gsfc.nasa.gov/tdrss/>***
5. Consultative Committee for Space Data Systems (CCSDS).
Copies of CCSDS Recommendations are available at: ***<http://www.ccsds.org/ccsds/>***